

STUDY OF ANATOMICAL VARIANCE OF THE ZYGOMATICOFACIAL FORAMEN AND DETERMINATION OF RELIABLE REFERENCE POINTS FOR SURGERY

Abbreviations:

ZFF: zygomaticofacial foramen

ZOF: zygomaticoorbital foramen

ZTF: zygomaticotemporal foramen

ABSTRACT

Dissection onto the facial aspect of the zygoma is common in procedures of the midface for traumatic injury, craniofacial deformity and cosmesis. These procedures carry risk of injury to the neurovascular structures exiting the zygomaticofacial foramen (ZFF). The purpose of the current study was to map the ZFF, and to determine reliable reference points from which to identify the ZFF pre- and peri-operatively. Secondly, we aimed to compare ZFF anatomy between sexes and geographical populations. 429 adult skulls from 9 geographic locations were used in the study. A cross-line laser was superimposed onto each zygoma to generate consistent landmarks (lines 1 and 2) from which to measure the ZFF, and the number of ZFF on each zygoma was documented. The location and frequency of ZFF differed significantly between geographic populations, but not between sexes. Of all 858 sides, 0 foramina were found in 16.3%, 1 foramen in 49.8%, 2 foramina in 29%, 3 foramina in 3.4% and 4 foramina in 1.4%. 93% of foramina were found within a 25mm diameter zone (ZFF zone) centred at 5mm anterior to the intersection of lines 1 and 2 on the right zygoma, and 94% were found within equivalent measurements on the left. Using these landmarks, we propose a novel method of identifying a ZFF zone irrespective of sex or geographic population. This technique may be of use in preventing iatrogenic damage to the ZFF neurovascular bundle during procedures of the midface and in local nerve block procedures.

INTRODUCTION

The zygomatic bone features three small openings, the zygomaticofacial foramen (ZFF) on the facial aspect, the zygomaticoorbital foramen (ZOF) on the orbital aspect and the zygomaticotemporal foramen (ZTF) on the temporal aspect, that transmit respective branches of the maxillary division of the trigeminal nerve (Figure 1). The zygomaticofacial nerve initially passes through the ZOF to enter the zygomatic bone. From here, it reaches the facial aspect of the zygomatic bone via the ZFF, and perforates the orbicularis oculi muscle to innervate the skin over the malar prominence.¹ The clinical applications of understanding ZFF anatomy are numerous. Dissection onto the facial aspect of the zygoma is often necessary in the management of facial trauma, deformity, craniofacial and some cosmetic procedures. These procedures carry inherent risk of damage to the zygomaticofacial neurovascular bundle. Indeed, haematoma formation secondary to tearing of the zygomaticofacial artery has been reported following osteotomies of the zygoma.^{2,3} Although injury to the zygomaticofacial neurovascular complex is not infrequent in trauma, injury during elective procedures of the zygoma may complicate post-operative recovery and increase operating times. An ability to predict ZFF location may ameliorate these complications. Moreover, the ZFF has been proposed as a landmark for directing the site of orbitozygomatic osteotomies, and understanding ZFF anatomy may facilitate the development of local nerve block procedures for lacerations over the malar aspect of the cheek.

Variation in the incidence, location and number of ZFF is well recognised, and may impact on surgical outcomes. Although studies have previously evaluated this variation in position and incidence of the ZFF, a reliable method of identifying the foramen in a clinical context has yet to be proposed.^{4–10} Thus, there were two objectives of this study. First, to determine reliable reference points in relation to which the location of the ZFF may be predicted in a clinical context. This should allow for delineation of surgical safe zones to prevent zygomaticofacial complex injury in procedures of the zygoma. Second, given previous speculation that ZFF anatomy may vary according to ethnicity, we aimed to comprehensively investigate ZFF anatomy according to both sex and geographic population.^{4,9}

METHODS

Dry adult skulls used in the study were obtained from the Leverhulme Centre for Human Evolutionary Studies, Cambridge. Samples from the following geographic locations were included in the study: Europe (England, Austria, France), North America (Zuni and Kechipawan tribes), New Zealand (Maori and Moriori tribes), New

Britain, Australia (Aboriginal Australians), South East Asia (Borneo), Africa (Tanzania), India (West Bengal, Maharashtra, Bihar, Punjab), and Middle East (Levant). These groups had been selected by anthropologists based on homogeneity of specimens, thereby allowing a reliable comparison of anatomy between ethnic groups. Only modern human crania were included to prevent evolutionary bias. A larger European sample was selected for robust analysis of ZFF anatomy according to sex. Where data were unavailable, skulls were sexed according to Walker (2008).¹¹ Skulls with an ambiguous sex, defined as having a mean ‘sex score’ of 2.75-3.25, were excluded from the study. Skulls with evidence of trauma or deformation affecting the facial skeleton were also excluded. A total of 429 skulls (858 sides) met the inclusion criteria for the study.

The number of ZFF was recorded on the left and right zygomas of each skull. Patency was confirmed using a wire probe. To produce consistent landmarks from which to measure the location of ZFF on the zygoma, a 40mW cross-line laser module was projected onto each skull with the horizontal line aligning with the Frankfurt plane (Line 1). The vertical line, at 90 degrees to the horizontal, was aligned with the posterior-most margin of the zygomatico-frontal suture (Line 2). The following measurements were taken from each zygoma: α , the distance from the ZFF to the closest point of the orbital margin; β , the distance from the ZFF to line 1, as measured parallel to line 2; γ , the distance from the ZFF to line 2, as measured parallel to line 1 (figure 2). These were made using a Mitutoyo ABSOLUTE AOS Digimatic Caliper (resolution of 0.01mm).

Statistical analysis was performed using R version 3.3.1. Given the unequal variances of samples in the ethnic group data, Wilcox’s “Robust Two-way ANOVA” with trimmed means was employed for comparison of foramina location between ethnic groups and sides.¹² “Two-way ANOVA” was used for comparison of foramina location between sexes and sides. “Log-linear analysis” was used for comparison of foramina number, with “Chi-Square tests” for follow up comparisons. Significance level was accepted as $P < 0.05$.

RESULTS

Comparison of sex

ZFF number

A total of 240 European skulls were used for comparison of ZFF anatomy between sexes: 88 female and 152 male specimens. For both male and female specimens, 1 foramen was most commonly identified (52% of male sides and 50% of female sides), followed by 2 foramina (25% of male sides and 31% of female sides). Three-way

loglinear analysis identified no significant differences in foramina number between either sides or sexes, producing a final model with a likelihood ratio of $\chi^2(10) = 7.38, P = 0.69$.

ZFF location

The mean distance of the ZFF from the orbital margin (measurement “ α ”) was significantly larger in males than females ($F(1,558) = 61.495, P < 0.001$) (Table 1); there was no significant difference between left and right sides ($F(1,558) = 0.548, P = 0.459$), and no interaction between side and sex ($F(1,558) = 0.86, P = 0.354$).

No difference was found on the vertical plane (distance “ β ”) between sexes ($F(1,558) = 0.470, P = 0.493$) or between sides ($F(1,558) = 2.112, P = 0.147$). Equally, there was no difference in location of ZFF in the horizontal plane (“ γ ”) between sexes ($F(1,558) = 0.655, P = 0.419$) or sides ($F(1,558) = 1.612, P = 0.205$). Refer to S1 for a visual representation of foramina location in male and female zygomas.

Comparison of geographic populations

ZFF number

A total of 429 skulls were used for a comparison of ethnic groups. Foramina number per side differed significantly between multiple different geographic populations ($\chi^2(44) = 28.81, P = 0.963$), but no difference in foramina frequency was identified between left and right sides ($\chi^2(36) = 28.81, P = 0.797$) (Table 2).

ZFF location

Distance “ α ” differed significantly between multiple different geographic populations ($F(8, 814) = 16.663, P < 0.001$), but no difference was found between left and right sides ($F(1, 814) = 1.064, P = 0.303$). ZFF location differed significantly on the vertical plane “ β ” between geographic populations but not between sides ($F(8,818) = 16.433, P < 0.001$ and $F(1,818) = 3.978, P = 0.410$, respectively). The same was true for ZFF location in the horizontal dimension “ γ ” ($F(8,829) = 14.411, P < 0.001$, and $F(1,818) = 14.911, P = 0.180$).

DISCUSSION

The zygomatic bone is formed through ossification within the maxillary prominence of the first pharyngeal arch. Evolutionarily, it serves in conjunction with the supraorbital ridge of the frontal bone to protect the eye. Owing to its anatomical position, the zygomatic bone is an important element of the facial skeleton for various surgical

procedures, including maxillary osteotomies, mid-face fracture repair, cosmetic surgery and procedures to access the cranial vault. In these procedures, dissection onto the facial aspect of the zygoma is commonplace. The ZFF is clinically significant due to both the possibility of damage to its associated neurovasculature, and the importance of its location as a landmark for osteotomy during certain surgical procedures. The ZFF has been proposed as a potential landmark for identifying the inferior orbital fissure for orbitozygomatic craniotomy, and also for marking the location of the orbitozygomatic osteotomy in order to avoid entering the maxillary sinus.^{5,13} The ability to approximate the location of the ZFF prior to a procedure would be a powerful tool in surgical planning. Moreover, predicting ZFF anatomy may facilitate the development of nerve blocks for local procedures in the malar region.

In the complete sample of 858 sides used in the current study, a single foramen was by far the most frequently identified ZFF number, found in 427 (49.8%) sides. Duplication of the ZFF was found in 250 (29%) sides and 3 foramina were found in 29 (3.4%) sides. The presence of 4 foramina was a rare occurrence, and found in just 12 (1.4%) sides. Foramina were absent in 140 (16.3%) sides. The results of previous studies on ZFF incidence are largely consistent with the findings of the present study. Loukas *et al.* (2008) reported 1 foramen in 40%, 2 foramina in 15%, 3 foramina in 5%, 4 foramina in 5% and 0 foramina in 39% of sides in a study of 200 skulls of mixed ethnic origin. Differences in the number of ZFF per zygoma and in foramina locations most likely reflect differences in contour, shape and size of the zygomatic bone between ethnic groups.⁸ Embryologically, these observed differences in both ZFF and ZOF location and number might reflect the position of bifurcation of the zygomaticofacial nerve within the mesenchyme.⁹

Although frequency of ZFF numbers per zygoma did not differ between males and females, relative ZFF frequencies were not uniform between geographic populations. These results reflect previous studies conducted on skulls from different ethnic populations.^{8–10,14} This variation may affect the validity of the ZFF as a surgical landmark. A previous study supported a single ZFF as a reliable predictor of inferior orbital fissure location for orbitozygomatic craniotomy in 96% of the studied specimens¹⁰; this percentage markedly dropped with more than 1 foramen. Thus, variation in incidence of different foramina numbers between ethnic groups may impact on surgical planning. Although it is not feasible to categorise every patient according to ethnicity, it is important for surgeons to recognise that this inter-group variation exists.

The location of ZFF was consistent between males and females with respect to lines 1 and 2. However, ZFF in males were significantly farther from the orbital margin than in females. Clinically, this is relevant as the orbital margin is an easily identified landmark encountered in the aforementioned surgical procedures.

A more pertinent and clinically significant consideration when discussing foramina location is where they are *not* present on the zygoma. Determining this would allow delineation of “surgical safe zones” to reduce risk of damaging the zygomaticofacial nerve and artery in procedures involving the facial aspect of the zygoma. Using Lines 1 and 2 (Figure 2), safe zones can be identified by calculating zones of ZFF occupancy based on our data (“ZFF zones”). With respect to the ZFF, the surgical safe zone may then be defined as any region on the zygoma beyond the boundaries of the ZFF zone. 100% of all ZFF, irrespective of ethnic group or sex, resided within a zone of 29.9mm x 25.07mm on the left zygoma (n = 522) and 30.65mm x 25.69mm on the right zygoma (n = 546). These zones, however, would be of little use in identifying the ZFF during surgery, and so modified ZFF zones were derived for clinical applicability. On the left zygoma, 92% of all ZFF fall beyond 5mm of the orbital margin, and 94% lie within a circle of 25mm diameter centred at 5mm anterior to the intersection point of lines 1 and 2. On the right zygoma, 92% of ZFF fall beyond 5mm of the orbital margin, and 93% of foramina fall within an equivalent circle of 25mm diameter. Both conservative and modified ZFF zones are illustrated in Figure 3. Where a zygoma featured multiple foramina, the mean distance between ZFF was 7.35mm (standard deviation of 3.26mm). Knowing this information may facilitate localisation of further foramina once the first has been identified.

In clinical practice the intersection of lines 1 and 2 may be identified using surface landmarks to allow the physician to identify the ZFF zone (Figure 4). The Frankfurt plane is identified as a line running between the superior margin of the tragus, which corresponds to the porion, and the inferior-most margin of the ipsilateral orbit. From this, line 2 can be determined through palpation of the zygomaticofrontal suture to identify the intersection point. Tracing 5mm anterior to this intersection point locates the centre of the modified ZFF zone, from which the entire zone can be delineated. Identifying the ZFF zone using surface anatomy may have applications in both operative planning and in administration of local nerve blocks for suturing of facial lacerations.

CONCLUSION

The clinical relevance of variation in ZFF location and number lies in both the application of ZFF location as a landmark for osteotomies in maxillofacial and craniofacial procedures, and also in the potential for damage to the structures emerging from it during zygomatic surgery. Surgeons should be aware of this anatomical variation to minimise the risks of complications. We propose a novel method of identifying a ZFF zone irrespective of sex or

ethnic group. This technique should be of use in directing osteotomy sites, local nerve blocks, and in preventing iatrogenic damage to the ZFF neurovascular bundle. The data provided herein should be of interest to the surgeon in training.

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CONFLICT OF INTEREST

The authors report no commercial or financial associations that might pose or create conflict with information presented in the manuscript.

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FIGURE LEGENDS

Figure 1. Anatomy of the zygomaticofacial and zygomaticotemporal nerves. (COLOUR IN PRINT)

Figure 2. Measured distances. LINE 1, a line aligning with the Frankfurt plane; LINE 2, a vertical line aligned with the posterior-most margin of the zygomaticofrontal suture at 90° to LINE 1; α , distance from ZFF to closest point of orbital margin; β , distance from ZFF to LINE 1, as measured parallel to LINE 2; γ , distance from ZFF to LINE 2, as measured parallel to LINE 1. (COLOUR IN PRINT)

Figure 3. Top panel: conservative ZFF zones. Bottom panel: modified ZFF zones, percentage indicates percentage of ZFF falling within modified zone. (COLOUR IN PRINT)

Figure 4. Delineation of the ZFF zone using surface landmarks.

Supplementary material 1 (S1). ZFF location and density plots in males and females for left and right zygomas. Axes correspond to positioning of lines 1 and 2 (Figure 2); measurements in millimetres.